



US008456697B2

(12) **United States Patent**
Mestha et al.

(10) **Patent No.:** **US 8,456,697 B2**
(45) **Date of Patent:** ***Jun. 4, 2013**

(54) **ADAPTIVE ILLUMINATION INDEPENDENT MATCHING OF SPOT COLORS**

(75) Inventors: **Lalit Keshav Mestha**, Fairport, NY (US); **Yao Rong Wang**, Webster, NY (US); **Alvaro Gil**, Rochester, NY (US)

(73) Assignee: **Xerox Corporation**, Norwalk, CT (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 616 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **12/504,332**

(22) Filed: **Jul. 16, 2009**

(65) **Prior Publication Data**

US 2011/0013206 A1 Jan. 20, 2011

(51) **Int. Cl.**

G06F 15/00 (2006.01)
H04N 1/40 (2006.01)
G06K 9/00 (2006.01)

(52) **U.S. Cl.**

USPC **358/1.9**; 358/2.1; 382/167

(58) **Field of Classification Search**

USPC 382/167
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,929,906 A * 7/1999 Arai et al. 348/223.1
6,157,469 A 12/2000 Mestha 358/504
6,639,669 B2 10/2003 Hubble, III 356/319
6,744,531 B1 6/2004 Mestha et al. 358/1.9
7,835,032 B2 * 11/2010 Sekine 358/1.9
8,107,141 B2 * 1/2012 Patrick et al. 358/527

2005/0030560 A1 * 2/2005 Maltz et al. 358/1.9
2006/0170994 A1 * 8/2006 MacKinnon et al. 358/518
2007/0153243 A1 7/2007 Mestha et al. 353/122
2007/0291312 A1 * 12/2007 Kaneko et al. 358/2.1
2008/0043263 A1 2/2008 Hancock et al. 358/1.9
2008/0043264 A1 2/2008 Gil et al. 358/1.9
2008/0043271 A1 2/2008 Gil et al. 358/1.9
2008/0218784 A1 9/2008 Ben-Chorin et al. 358/1.9
2010/0228511 A1 * 9/2010 Chin et al. 702/82

OTHER PUBLICATIONS

Braun et al., Development and Evaluation of Six Gamut-Mapping Algorithms for Pictorial Images, The Seventh Color Imaging Conference, 1999, Digital Imaging Technology Center, Xerox Corporation, Webster, NY.

Montag et al., Gamut Mapping: Evaluation of Chrome Clipping Techniques for Three Destination Gamuts, The Sixth Color Imaging Conference: Science, Systems and Applications, 1998, Rochester Institute of Technology, Rochester, NY.

Montag et al., Psychophysical Evaluation of Gamut Mapping Techniques Using Simple Rendered Images and Artificial Gamut Boundaries, IEEE Transactions on Image Processing, Jul. 1997, vol. 6, No. 7.

(Continued)

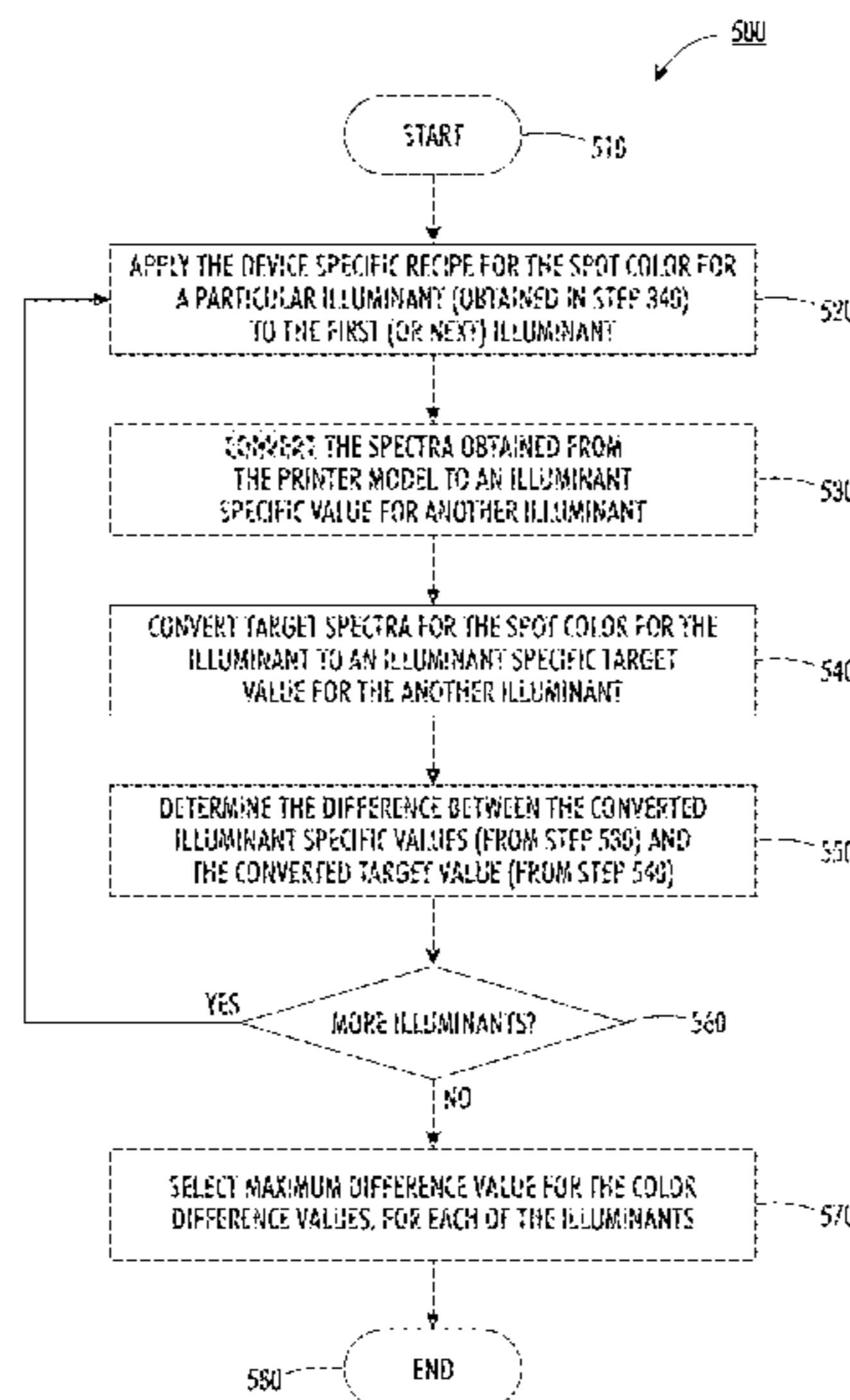
Primary Examiner — Barbara Reinier

(74) *Attorney, Agent, or Firm* — Pillsbury Winthrop Shaw Pittman, LLP

(57) **ABSTRACT**

A methodology is disclosed to achieve adaptive illumination independent matching of spot colors. In one embodiment, the methodology includes an iterative process to determine a variety device specific recipes for spot colors across different illumination spectra, and then automatically choosing and/or recommending the optimal recipe that provides the lowest color dispersion across a variety of illuminants under consideration. This approach may be used with a variety of gamut mapping techniques. According to a further embodiment, the methodology may be used with a ray-based gamut mapping method.

35 Claims, 16 Drawing Sheets



OTHER PUBLICATIONS

Explanation of Various Light Sources and Their Use in Visual Color Matching Applications, GTI TrueLight TrueColor, GTI Graphic Technology, Newburgh, NY.

Srinivas et al., Genetic Algorithms: A Survey, IEEE Computer Magazine, Jun. 1994, pp. 17-26.

Torczon, On the Convergence of the Multidirectional Search Algorithm, SIAM Journal Optimization, Feb. 1991.

Illumination Sensor, Mar. 2002, Climatronics Corporation, Bohemia, NY.

Metamerism Index, Applications Note, Insight on Color, 2008, vol. 9, No. 4.

Color Inconstancy, Applications Note, Insight on Color, 2008, vol. 12, No. 11.

Imai et al., Comparative Study of Metrics for Spectral Match Quality, Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY.

Standard Illuminant, obtained on Jul. 31, 2009 from Wikipedia at http://en.wikipedia.org/wiki/Standard_illuminant.

Mestha et al., Fundamentals of Color Engineering, Appendix A of Control of Color Imaging Systems, May 2009, CRC Press, ISBN 978-0-8493-3746-8.

Lagarias et al., Convergence Properties of the Nelder Mead Simplex Algorithm in Low Dimensions, Technical Report 96-4-07, May 1, 1997, Bell Laboratories, Murray Hill, NJ.

* cited by examiner

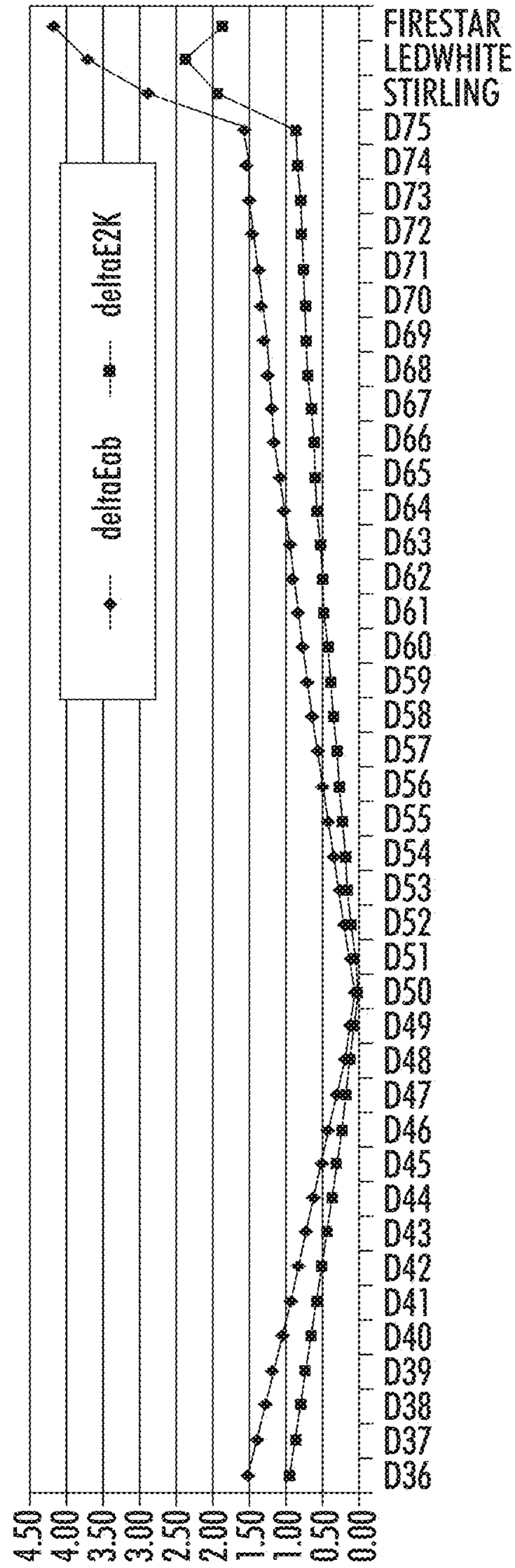


FIG. 1a

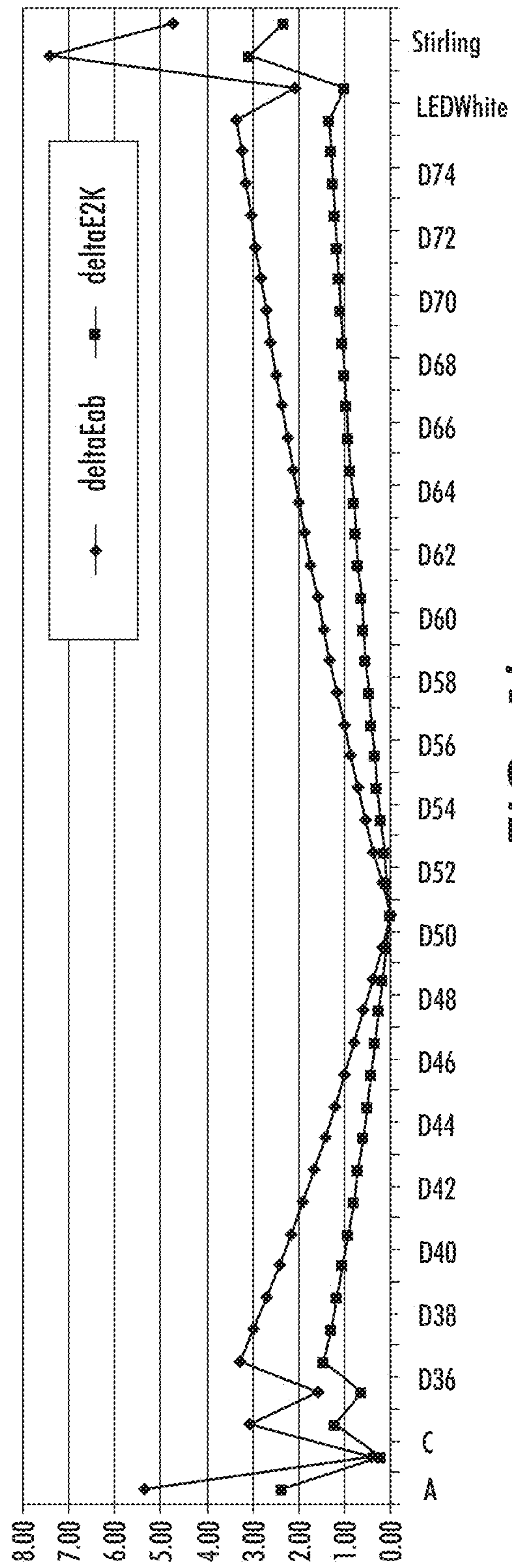


FIG. 1b

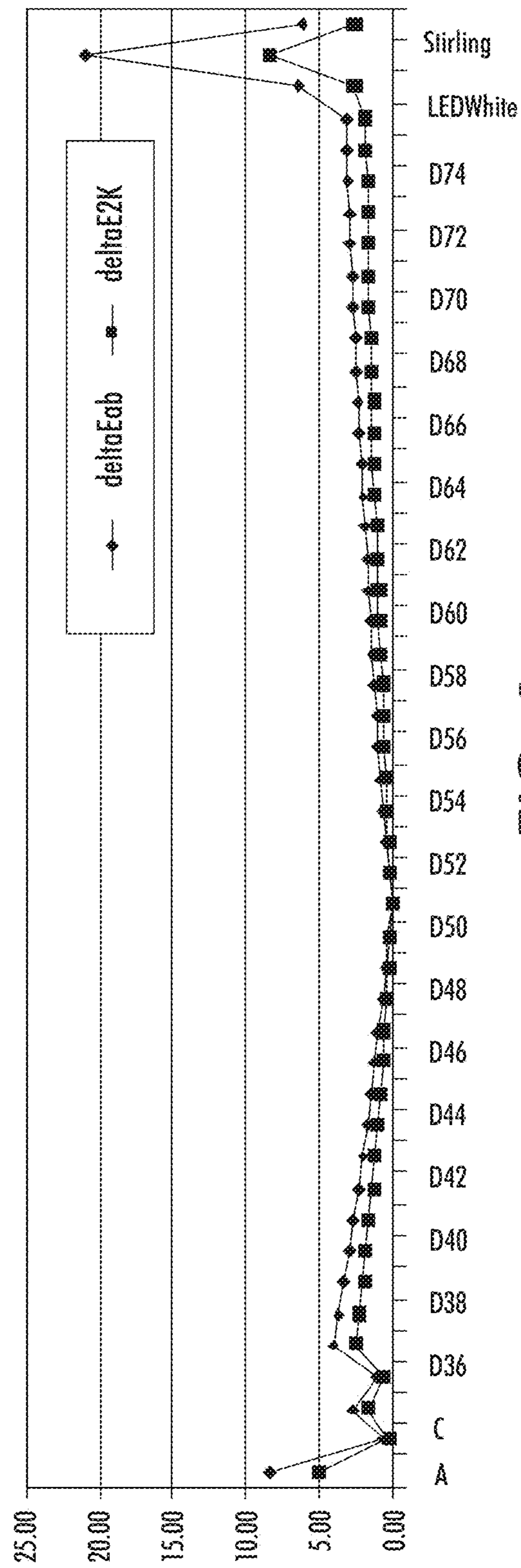


FIG. 1C

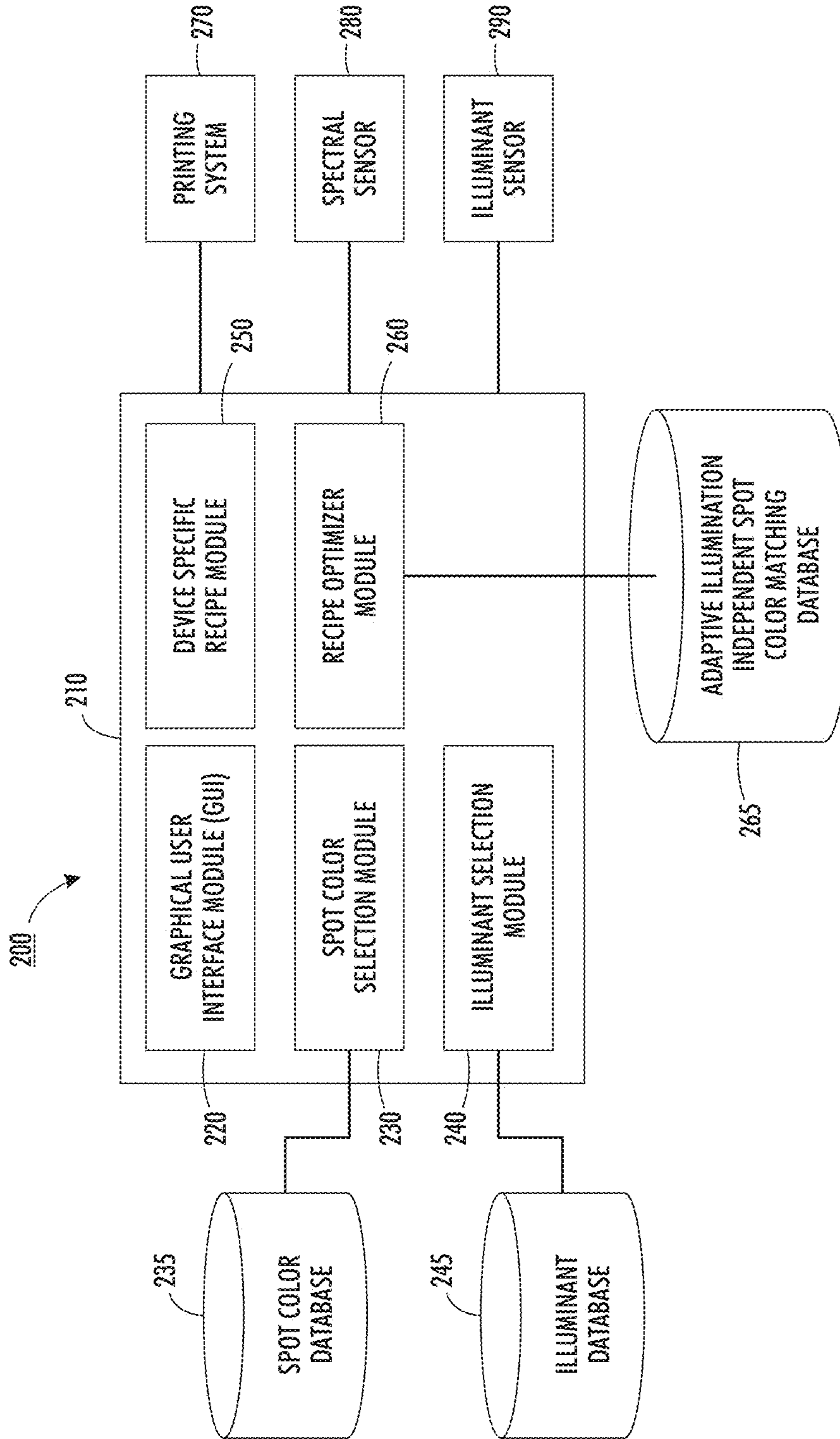


FIG. 2

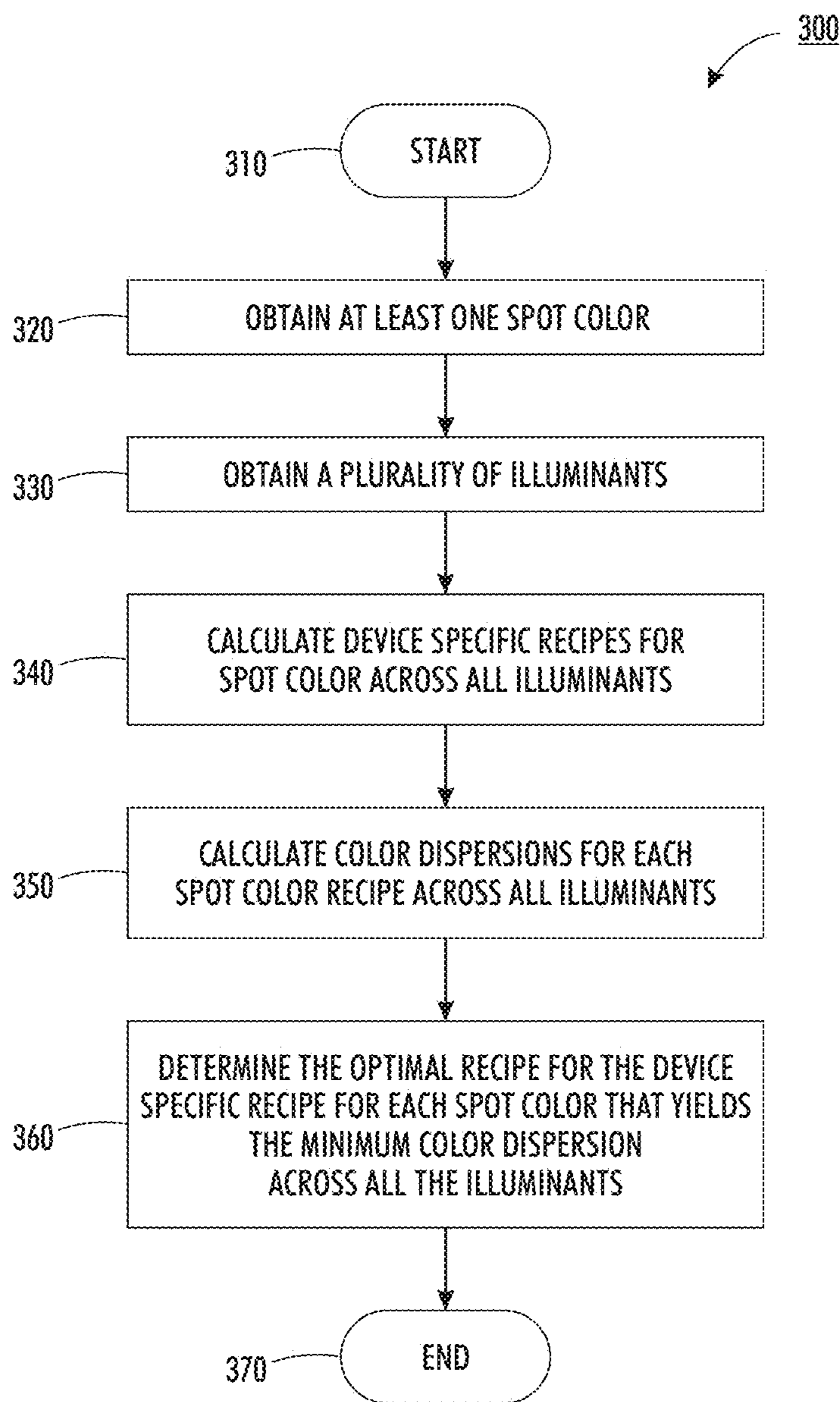


FIG. 3

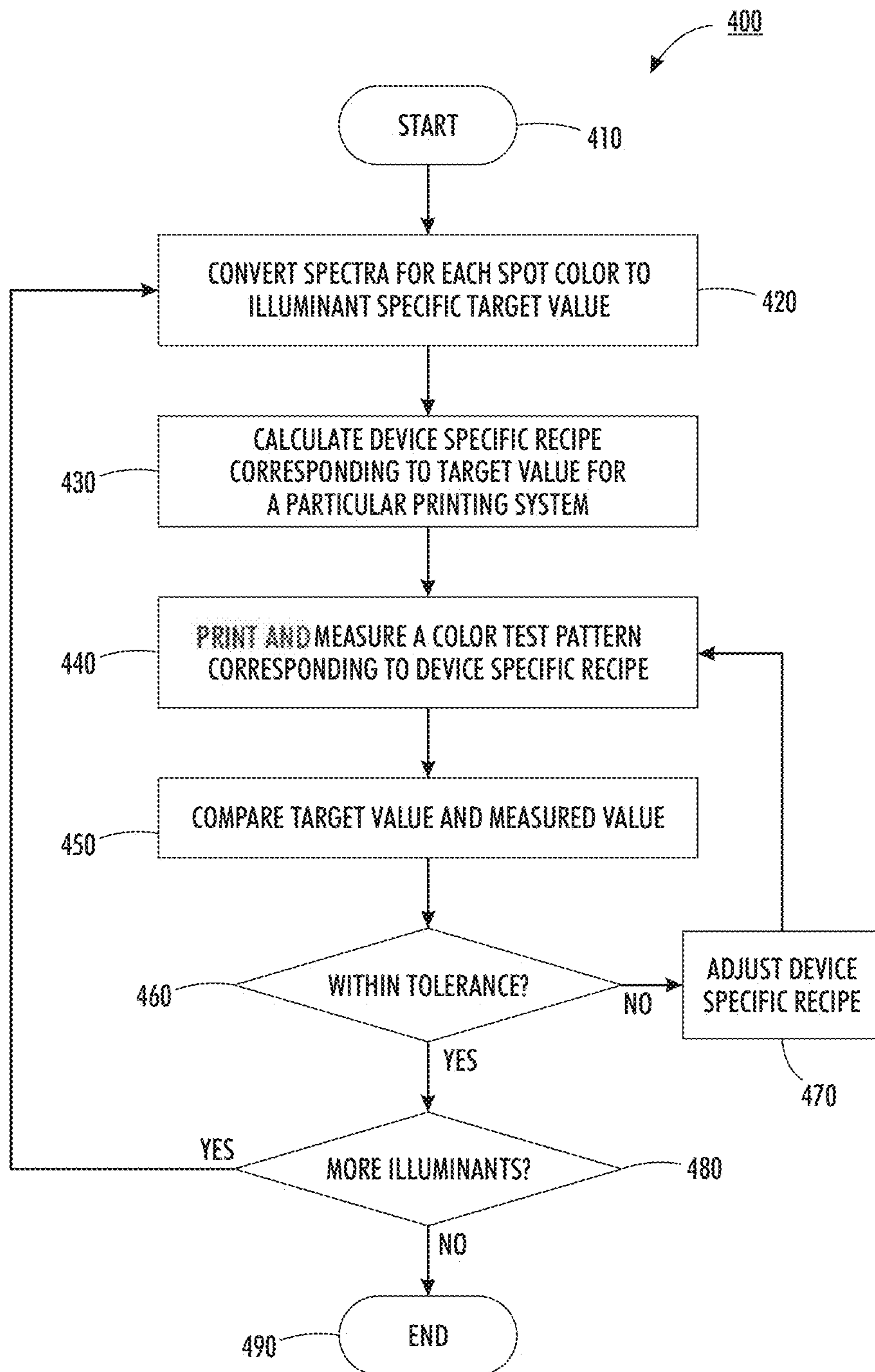


FIG. 4

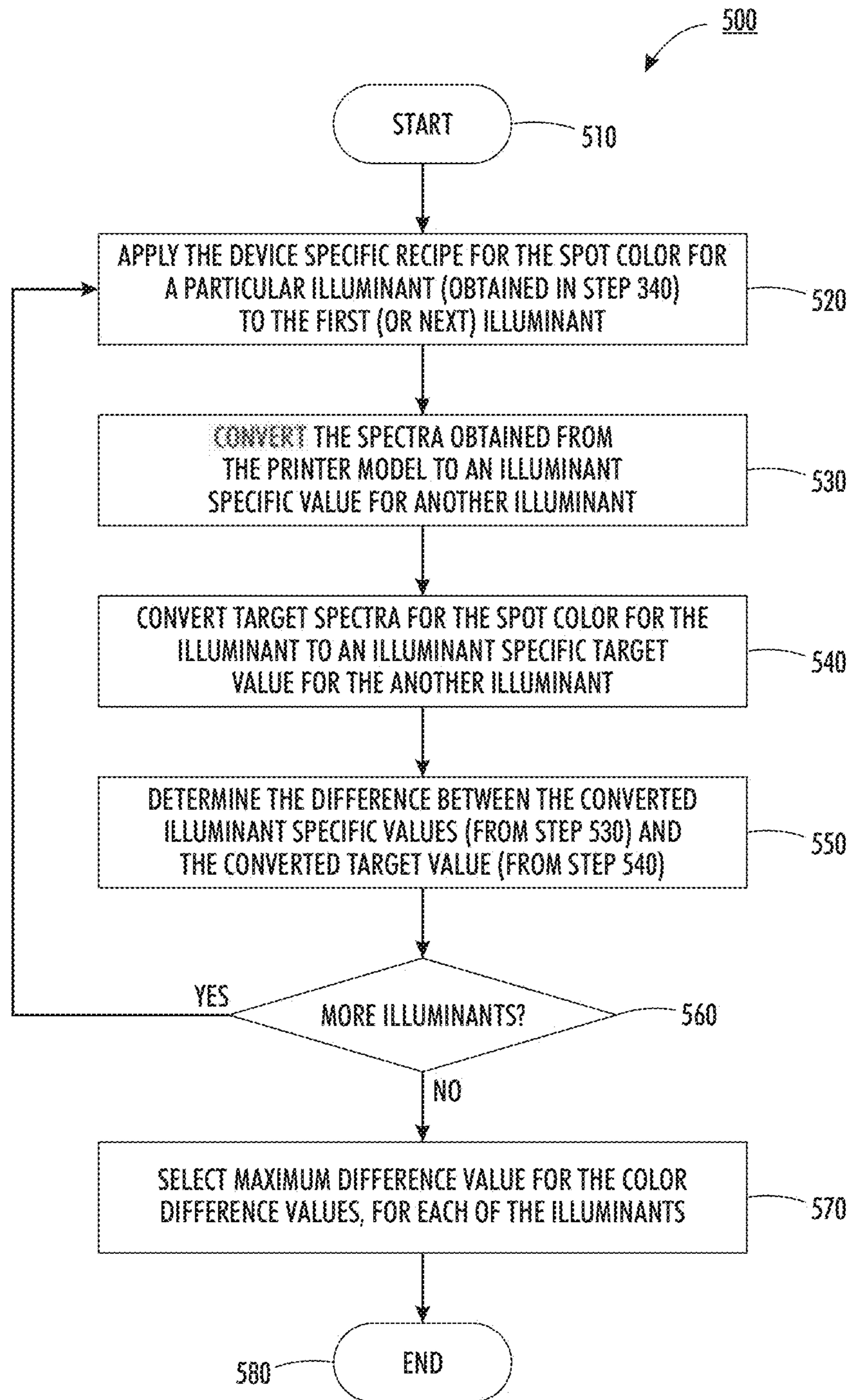


FIG. 5

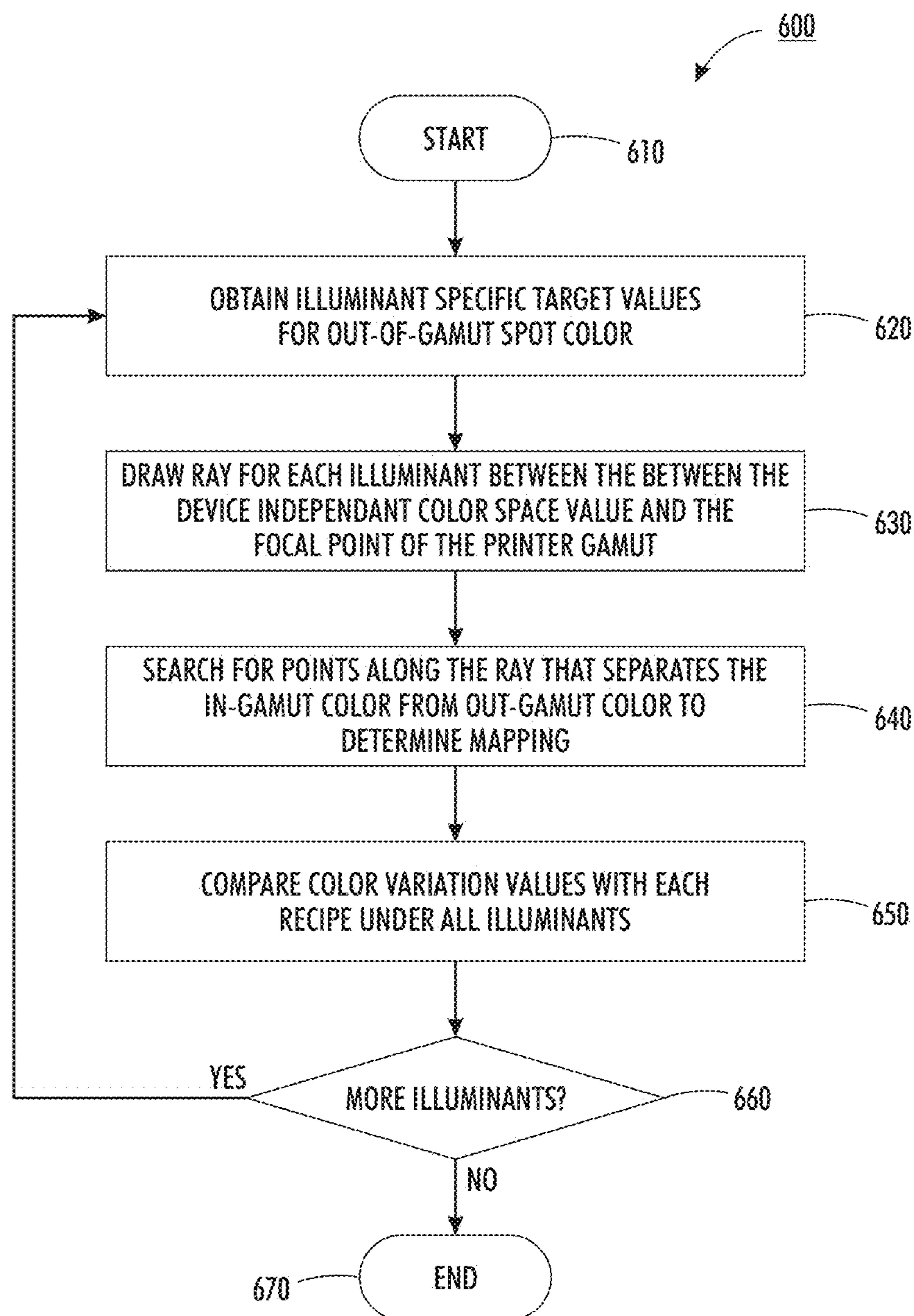


FIG. 6

ILLUMINANT	MAXIMUM SPREAD (E _{ab})	MAXIMUM SPREAD (2000)	BEST C	BEST M	BEST Y	BEST K
D36	6.49	3.08	4	214	139	129
D37	6.29	2.98	4	214	140	129
D38	6.09	2.88	4	213	140	129
D39	5.91	2.78	4	213	141	130
D40	5.73	2.69	4	213	141	130
D41	5.55	2.61	3	213	142	130
D42	5.38	2.52	3	213	142	130
D43	5.22	2.44	3	212	143	130
D44	5.07	2.37	3	212	143	130
D45	4.92	2.29	3	212	144	130
D46	4.77	2.22	3	212	144	130
D47	4.63	2.24	3	212	144	130
D48	4.50	2.30	3	212	145	131
D49	4.37	2.36	3	211	145	131
D50	4.25	2.41	3	211	145	131
D51	4.13	2.46	3	211	145	131
D52	4.02	2.51	3	211	146	131
D53	4.00	2.55	2	211	146	131
D54	4.07	2.60	2	211	146	131
D55	4.13	2.64	2	211	146	131
D56	4.19	2.68	2	210	147	131
D57	4.25	2.72	2	210	147	131
D58	4.31	2.76	2	210	147	131
D59	4.36	2.80	2	210	147	131
D60	4.42	2.83	2	210	147	131
D61	4.47	2.87	2	210	148	132
D62	4.52	2.90	2	210	148	132
D63	4.56	2.93	2	210	148	132
D64	4.61	2.96	2	210	148	132
D65	4.65	2.99	2	209	148	132
D66	4.70	3.02	2	209	148	132
D67	4.74	3.05	2	209	148	132
D68	4.78	3.07	2	209	149	132
D69	4.82	3.10	2	209	149	132
D70	4.85	3.12	2	209	149	132
D71	4.89	3.15	2	209	149	132
D72	4.93	3.17	2	209	149	132
D73	4.96	3.19	2	209	149	132
D74	4.99	3.22	2	209	149	132
D75	5.03	3.24	2	209	149	132
Stirling	6.51	4.24	1	206	153	131
LEDWhite	8.26	4.66	9	214	129	130
Firestar	6.36	4.12	2	205	151	133

FIG. 7

ILLUMINANT	MAXIMUM SPREAD (E _{ab})	MAXIMUM SPREAD (2000)	BEST C	BEST M	BEST Y	BEST K
D36	5.60	3.30	4	0	90	27
D37	5.52	3.25	4	0	90	27
D38	5.43	3.21	4	0	90	27
D39	5.35	3.17	4	0	91	27
D40	5.27	3.13	4	0	91	27
D41	5.19	3.08	3	0	91	27
D42	5.11	3.04	3	0	91	27
D43	5.03	3.00	3	0	91	27
D44	4.94	2.95	3	0	91	27
D45	4.85	2.90	3	0	92	26
D46	4.76	2.85	3	0	92	26
D47	4.69	2.82	3	0	92	26
D48	4.60	2.77	3	0	92	26
D49	4.54	2.73	3	0	92	26
D50	4.45	2.69	3	0	92	26
D51	4.39	2.66	3	0	93	26
D52	4.30	2.60	3	0	93	26
D53	4.25	2.58	2	0	93	26
D54	4.20	2.55	2	0	93	26
D55	4.15	2.52	2	0	93	26
D56	4.06	2.47	2	0	93	26
D57	4.01	2.45	2	0	93	26
D58	3.97	2.42	2	0	93	26
D59	3.93	2.40	2	0	94	26
D60	3.88	2.38	2	0	94	26
D61	3.85	2.36	2	0	94	26
D62	3.75	2.30	2	0	94	26
D63	3.72	2.29	2	0	94	26
D64	3.68	2.27	2	0	94	26
D65	3.65	2.25	2	0	94	26
D66	3.62	2.24	2	0	94	26
D67	3.61	2.22	2	0	94	26
D68	3.64	2.21	2	0	94	26
D69	3.72	2.14	2	0	94	25
D70	3.74	2.13	2	0	94	25
D71	3.77	2.12	2	0	95	25
D72	3.79	2.11	2	0	95	25
D73	3.81	2.10	2	0	95	25
D74	3.84	2.08	2	0	95	25
D75	3.86	2.07	2	0	95	25
LEDWhite	7.45	4.23	1	0	86	26
Firestar	6.08	3.81	9	0	90	31
Stirling	6.81	3.66	2	0	100	19

FIG. 8

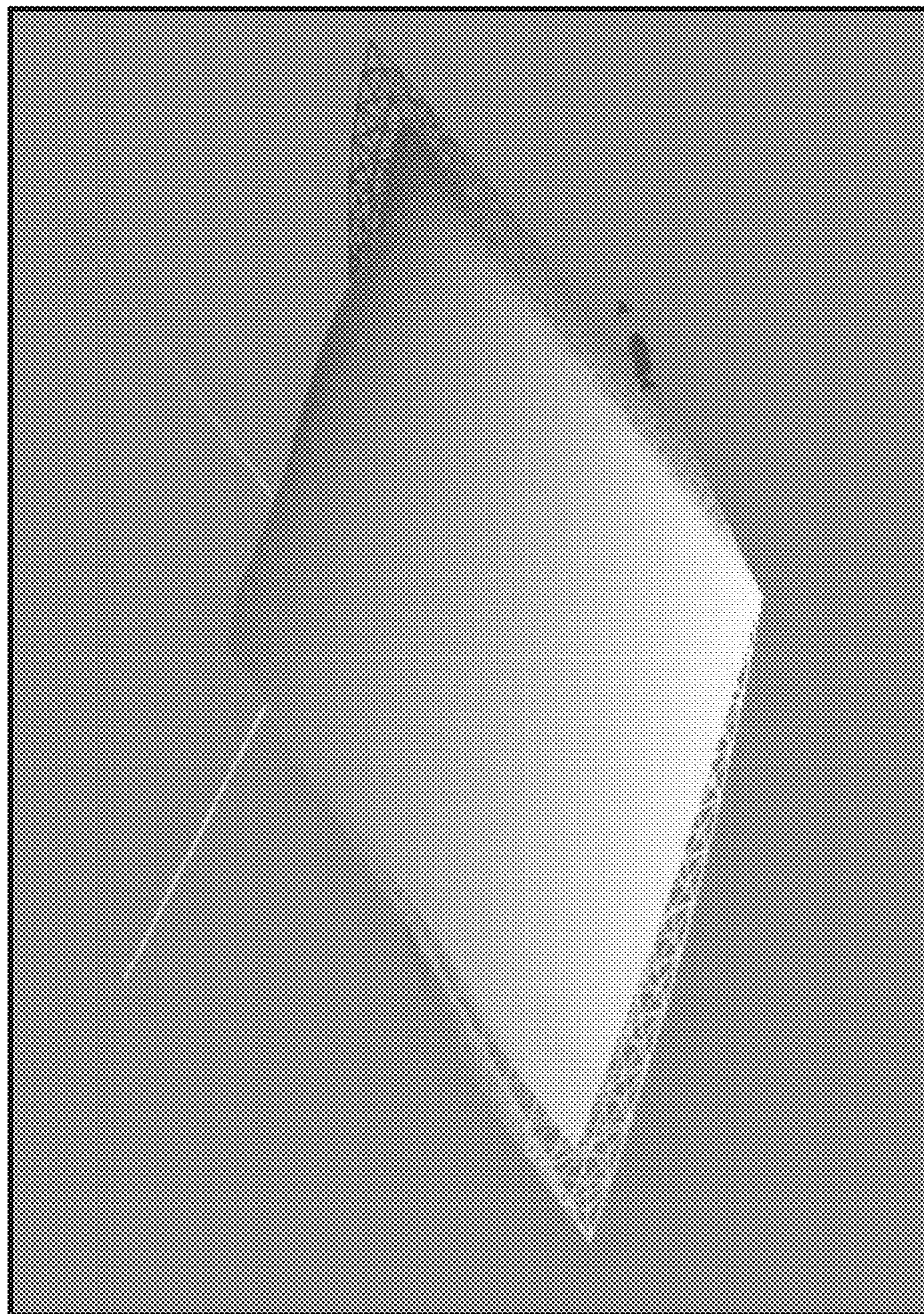


FIG. 9

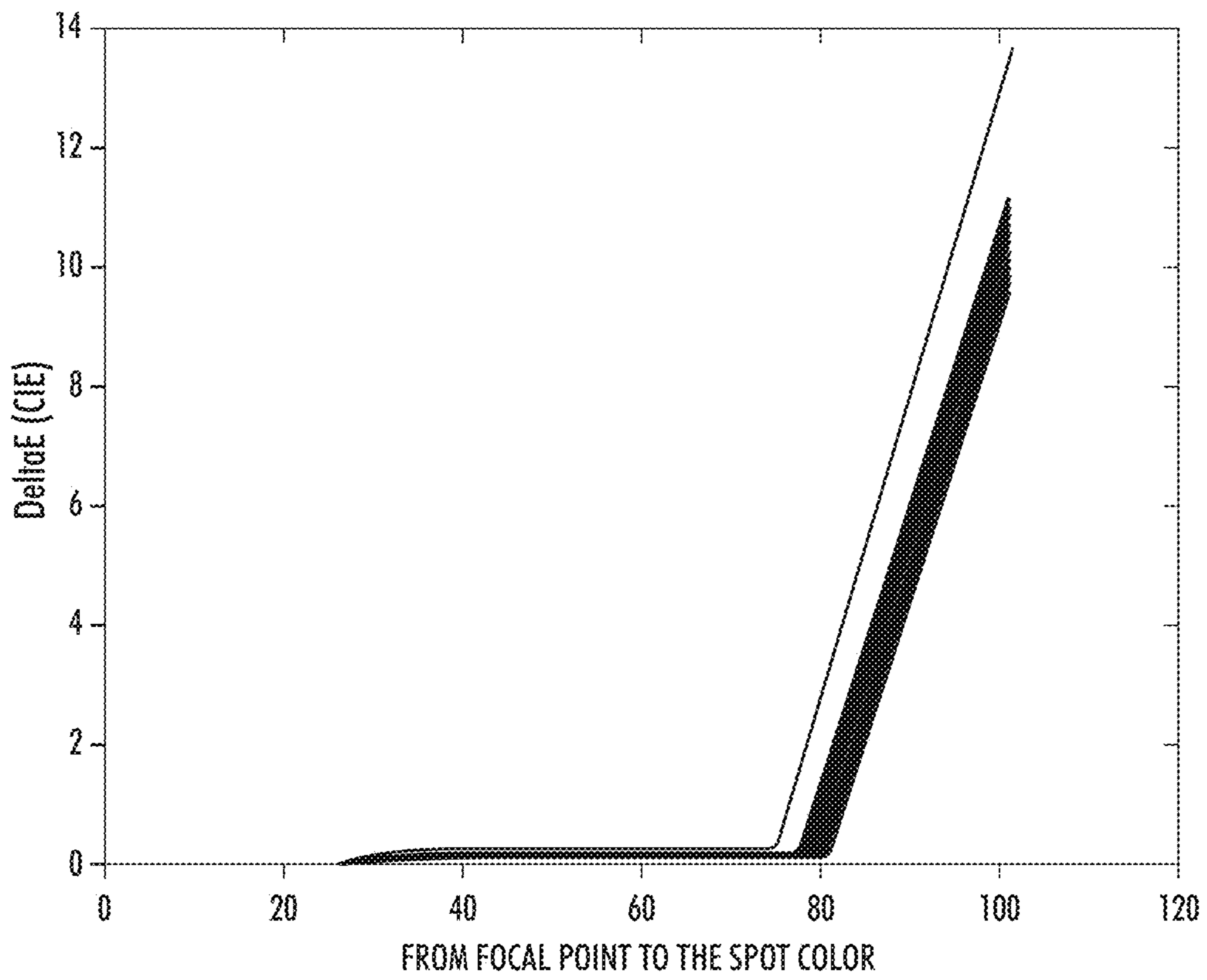


FIG. 10

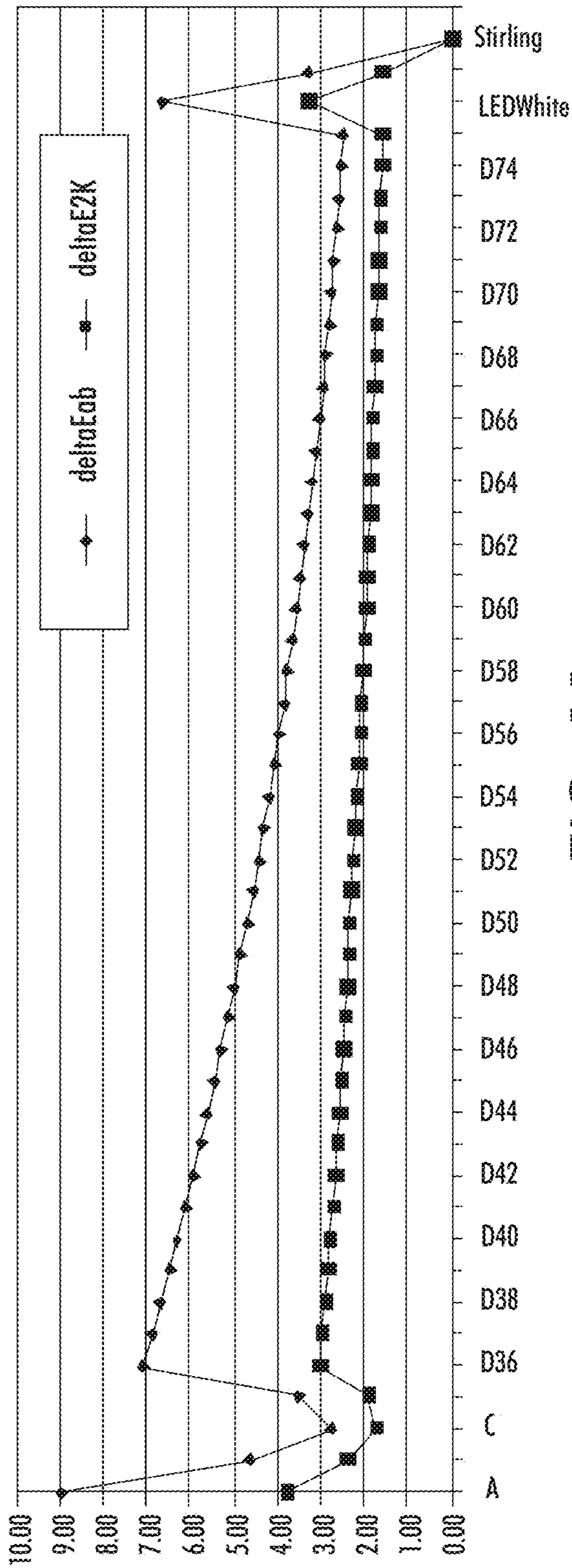


FIG. 11a

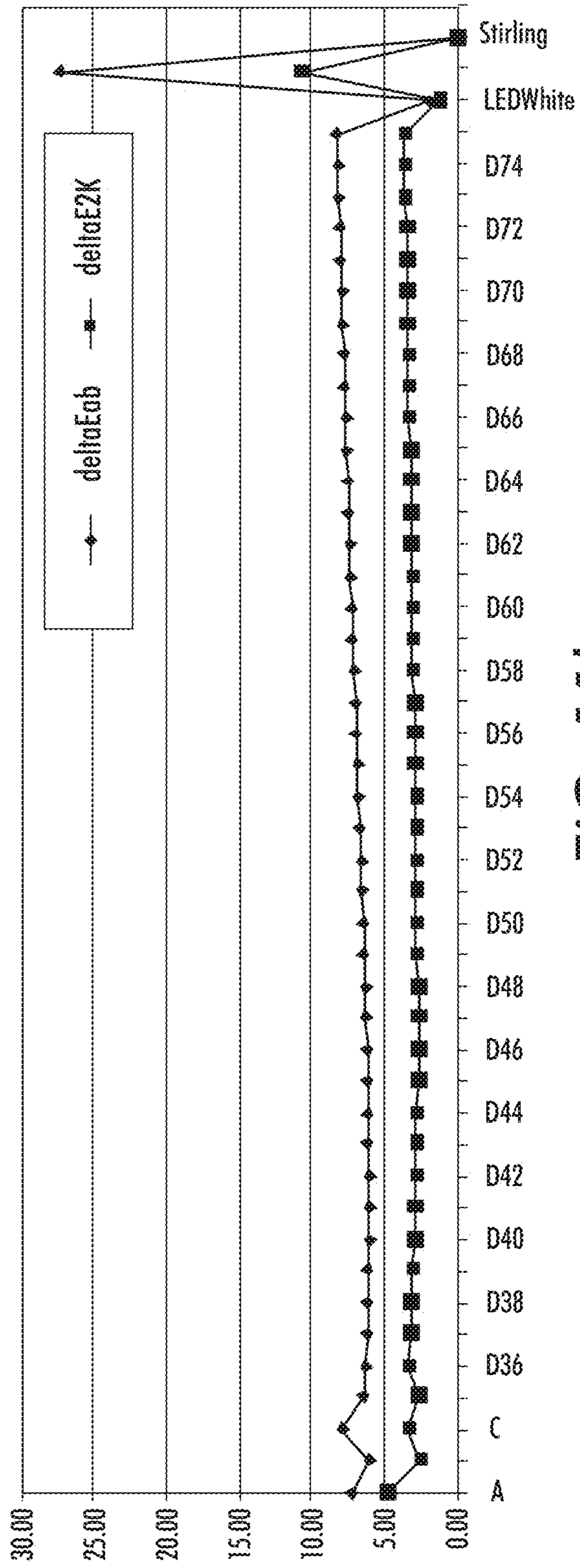


FIG. 17b

Illuminant	Maximum Spread (Eab)	Maximum Spread (2000)	Best C	Best M	Best Y	Best K
A	12.69	5.13	70	123	0	3
B	7.30	3.07	68	120	0	2
C	8.18	3.47	68	119	0	2
E	6.74	2.91	66	119	0	3
D36	10.42	4.17	70	122	0	3
D37	10.14	4.06	70	21	0	3
D38	9.86	3.96	70	121	0	4
D39	9.74	3.89	70	122	0	2
D40	9.48	3.80	70	122	0	2
D41	9.23	3.71	70	122	0	2
D42	8.99	3.63	70	121	0	3
D43	8.76	3.55	69	121	0	3
D44	8.53	3.47	69	121	0	3
D45	8.31	3.39	69	121	0	3
D46	8.10	3.32	69	120	0	3
D47	7.89	3.25	69	120	0	4
D48	7.69	3.18	69	120	0	4
D49	7.61	3.13	69	121	0	2
D50	7.42	3.06	69	121	0	2
D51	7.24	3.00	69	120	0	2
D52	7.06	2.93	69	120	0	2
D53	6.88	2.87	69	120	0	3
D54	6.71	2.81	69	120	0	3
D55	6.54	2.74	69	120	0	3
D56	6.38	2.75	69	120	0	3
D57	6.39	2.80	69	120	0	3
D58	6.52	2.85	68	119	0	3
D59	6.65	2.90	68	119	0	3
D60	6.77	2.95	68	119	0	4
D61	6.89	3.00	68	119	0	4
D62	7.01	3.04	68	119	0	4
D63	7.21	3.11	69	120	0	2
D64	7.32	3.15	69	120	0	2
D65	7.43	3.19	69	119	0	2
D66	7.54	3.23	69	119	0	2
D67	7.64	3.27	69	119	0	2
D68	7.74	3.31	69	119	0	2
D69	7.83	3.35	69	119	0	2
D70	7.93	3.38	68	119	0	2
D71	8.02	3.42	68	119	0	2
D72	8.11	3.45	68	119	0	3
D73	8.19	3.49	68	119	0	3
D74	8.28	3.52	68	119	0	3
D75	8.36	3.55	68	118	0	3
LEDWhite	8.91	3.84	77	121	0	2
Firestar	12.37	5.05	71	121	0	2
Stirling	9.00	3.81	68	118	0	2

FIG. 12

Illuminant	Maximum Spread (Eab)	Maximum Spread (2000)	Best C	Best M	Best Y	Best K
A	30.21	13.34	167	0	109	3
B	21.39	8.60	162	0	104	3
C	18.66	7.21	160	0	102	3
E	20.56	8.16	161	0	104	3
D36	24.83	10.72	164	0	106	4
D37	24.37	10.47	164	0	105	4
D38	24.21	10.30	165	0	106	2
D39	23.81	10.08	164	0	105	2
D40	23.43	9.88	164	0	105	3
D41	23.07	9.69	163	0	105	3
D42	22.74	9.51	163	0	104	3
D43	22.43	9.34	62	0	104	4
D44	22.39	9.23	163	0	105	2
D45	22.11	9.08	163	0	104	2
D46	21.85	8.94	163	0	104	2
D47	21.60	8.81	162	0	104	3
D48	21.37	8.68	162	0	104	3
D49	21.14	8.57	162	0	103	3
D50	20.93	8.46	161	0	103	3
D51	20.73	8.35	161	0	103	4
D52	20.54	8.25	161	0	103	4
D53	20.36	8.16	161	0	103	4
D54	20.42	8.10	162	0	103	2
D55	20.25	8.02	161	0	103	2
D56	20.10	7.94	161	0	103	2
D57	19.94	7.86	161	0	103	2
D58	19.80	7.78	161	0	103	3
D59	19.66	7.71	161	0	103	3
D60	19.53	7.65	160	0	103	3
D61	19.40	7.58	160	0	102	3
D62	19.28	7.52	160	0	102	3
D63	19.16	7.46	160	0	102	3
D64	19.04	7.41	160	0	102	3
D65	18.94	7.35	160	0	102	3
D66	18.83	7.30	159	0	102	4
D67	18.73	7.25	159	0	102	4
D68	18.63	7.20	159	0	102	4
D69	18.53	7.16	159	0	102	4
D70	18.44	7.11	159	0	102	4
D71	18.56	7.10	160	0	102	2
D72	18.47	7.06	160	0	102	2
D73	18.39	7.02	160	0	102	2
D74	18.31	6.98	160	0	102	2
D75	18.23	6.94	160	0	102	2
LEDWhite	26.55	10.56	159	0	102	3
Firestar	27.13	13.11	156	0	95	3
Stirling	27.39	10.62	168	0	107	3

FIG. 13

1

ADAPTIVE ILLUMINATION INDEPENDENT
MATCHING OF SPOT COLORS

FIELD

This application generally relates to the management and reproduction of spot colors by a printing system, and in particular, adaptive illumination independent matching of spot colors.

BACKGROUND

Spot colors are recognized as standardized colors. Some of the known spot color classification systems include: Pantone®, Toyo, DIC, American Newspaper Publishers Association (ANPA), and HKS. Accurate printing of spot colors is important to achieve a good color match to the original hard-copy proof on paper.

Standard spot color proofs are typically supplied by vendors, such as Pantone®, in the form of samples which can be separated for measurement and viewing. They may also be supplied in the form of swatch books. Spot colors are often used, or can be used, for large background areas, which may be the most color critical portion of a particular page.

Many software packages have the ability to enter or create device dependant recipes, such as Cyan, Magenta, Yellow and Black (CMYK) recipes, using multi-dimensional profiles for a particular spot color and store them for future use. These software packages may also allow users to manually edit the recipe.

A problem, however, with this approach is that the CMYK recipe that was originally entered and/or obtained through manual entry may not be very accurate at the time of reproducing the spot colors due to (a) variations in the print engine state, (b) operator error associated with manual adjustments or modifications to CMYK recipe values; and (c) inaccurate recipes to begin with.

An automated software application “Spot Color Control” (SCC) based on the Xerox Corp.’s “Automated Spot Color Editing (ASCE)” technology is currently available for use with inline sensors for the Xerox Corp.’s iGen3® and DC8000® Digital Production Presses. This technology uses an iterative process to find the device specific recipe under a D50 illuminant. While the printed spot colors may appear matched to the hardcopy proof under D50 light source, those colors may not “look” the same when viewed under other light sources.

The conventional techniques used for matching spot colors are optimized to a 2 degree observer and a D50 light source. Thus, even if the spot colors are matched under the D50 illuminant, they may look different when viewed under different angles.

FIG. 1(a) shows color variations for a Pantone® 202C spot color under multiple illuminants. The spot color has a near perfect match under the D50 light source (i.e., delta-E values are approximately zero). However, the figure shows the expected delta-E variations across other D series illuminants (D series with correlated color temperature from 3600 to 7500, or D36 to D75), Stirling fluorescence lamp, white LED, and Firestar fluorescence lamp. The maximum spread across the selected group of illuminants is about 4.25 delta-E 1976 (“deltaEab”) and 2.41 delta-E 2000 (“deltaE2K”).

FIG. 1(b) shows color variations for a Pantone® 251C spot color, which is outside the gamut of a printer, across multiple illuminants when this out-of-gamut spot color is mapped for a gamut with D50 illuminant and a 2 degree observer.

2

FIG. 1(c) shows color variations for a Pantone® 3385C spot color which is again outside the gamut of a printer, across multiple illuminants when this out-of-gamut spot color is mapped for a gamut with D50 illuminant and a 2 degree observer.

A seasoned color expert (human) may be able to recommend which light sources are best to use for a specific color matching application. However, due to variety of light sources available this may be difficult. Also, the light sources used for viewing may vary depending on environmental factors (e.g., humidity, temperature, ambient lighting conditions, location and geometry of the light source, etc.), which are difficult to control.

SUMMARY

According to one embodiment, a method for adaptive illumination independent matching of spot colors for a printing system comprises: obtaining spectra for at least one spot color; obtaining spectra for a plurality of illuminants; converting the at least one spot color spectra to an illuminant specific target spectra corresponding to each of the plurality of illuminants; determining a device specific recipe for each of the target spectra for the printing system; calculating a color dispersion value for each of the plurality of illuminants based on the device specific recipes by printing test patterns; and selecting a device specific recipe for the at least one spot color that yields the lowest color dispersion across the plurality of illuminants.

According to another embodiment, a system for adaptive illumination independent matching of spot colors for a printing system comprises: a print engine configured to render color; a sensor configured to measure spectra for a printed color; and a processor configured to: (i) convert at least one spot color spectra to an illuminant specific target spectra corresponding to each of a plurality of illuminants; (ii) determine a device specific recipe for each of the target spectra for the printing system; (iii) calculate a color dispersion value for each of the plurality of illuminants based on the device specific recipes by printing test patterns; and (iv) select a device specific recipe for the at least one spot color that yields the lowest color dispersion across the plurality of illuminants.

According to yet another embodiment, a computer-readable storage medium comprises computer-readable instructions stored therein that when executed by a processor are configured to implement a method for adaptive illumination independent matching of spot colors for a printing system.

Other features of one or more embodiments of this disclosure will seem apparent from the following detailed description, and accompanying drawings, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present disclosure will now be disclosed, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, in which:

FIGS. 1(a)-(c) show color variations for various spot color under multiple illuminants;

FIG. 2 shows an exemplary system for adaptive illumination independent matching of spot colors according to an embodiment;

FIG. 3 shows an exemplary method for adaptive illumination independent matching of one or more spot colors according to an embodiment;

FIG. 4 shows an exemplary method for determining device specific recipes for a spot color according to an embodiment;

FIG. 5 shows an exemplary method for calculating maximum color dispersion values for all illuminants according to an embodiment;

FIG. 6 shows an exemplary ray-based gamut mapping method for determining device specific recipes according to an embodiment;

FIG. 7 shows exemplary data for a Pantone® 202c spot color which is included in the printer gamut;

FIG. 8 shows exemplary data for a Pantone® 321c spot color which is outside of the printer gamut;

FIG. 9 shows a representation of the printer gamut for a spot color under different illuminants;

FIG. 10 shows a sudden rise of the delta-E values along the ray, which determines the mapping point in an out-of-gamut mapping;

FIGS. 11(a) and 11(b) show the dispersion of the colors from the CMYK recipe at the knee of the curve for different illuminants;

FIG. 12 shows exemplary data for a Pantone® 251C spot color which is outside of the printer gamut; and

FIG. 13 shows exemplary data for a Pantone® 3385C spot color which is outside of the printer gamut.

DETAILED DESCRIPTION

A methodology is disclosed to achieve adaptive illumination independent matching of spot colors. In one embodiment, the methodology includes an iterative process to determine a variety of device specific recipes for spot colors across different illumination spectra, and then automatically choosing and/or recommending the optimal recipe that provides lowest color dispersion value across a variety of illumination spectra under consideration.

This approach may be used with a variety of gamut mapping techniques, for example, disclosed in U.S. patent application Ser. No. 12/291,473 filed Feb. 24, 2009; U.S. Patent Application Publication No. 2008/00543264, and K. M. Braun, R. Balasubramanian, and R. Eschbach, "Development and evaluation of six gamut-mapping algorithms for pictorial images," The Seventh Color Imaging Conference, pp. 144-148 (1999), herein incorporated by reference in their entireties. According to a further embodiment, the methodology may be used with a ray-based gamut mapping technique.

The gamut mapping techniques may be used for both printing and non-printing devices. One non-printing device includes a display device having tunable individually-addressable Fabry-Perot membranes. See, e.g., U.S. Patent Application Publication No. 2007/0153243, herein incorporated by reference in its entirety. Any discussion of any specific printing or non-printing devices herein is not to be construed as limiting.

FIG. 2 shows an exemplary system 200 for adaptive illumination independent matching of spot colors according to an embodiment.

The system 200 may include an application 210 having a plurality of modules, including but not limited to, a graphical user interface module 220, a spot color selection module 230, an illuminant selection module 240, a device specific recipe module 250, and a recipe optimizer module 260. One or more of the modules comprising application 210 may be combined and/or include additional modules.

The application 210 may interface with one or more additional systems, such as a spot color database 235, an illuminant database 245, and an adaptive illumination independent spot color matching database 265. Moreover, the application interfaces with a printing system 270, a spectral sensor 280,

and optionally an illumination sensor 290. For some purposes, not all modules and elements may be necessary.

According to one embodiment, the application 210 may be software (firmware) created using any number of programming languages. Of course, it will be appreciated any number of hardware implementations, programming languages, and operating platforms may be used. As such, the description or recitation of any specific hardware implementation, programming language, and operating platform herein is exemplary only and should not be viewed as limiting.

The application 210 may be stored on a computer- or machine-readable storage media having computer or machine-executable instructions executable by a processor. In one implementation, the application 210 may reside on a memory of the print controller of a printing system or the printing system itself.

Alternatively, or additionally, the application 210 may be a stand-alone application running on a computer which interfaces with a printing system, for example, through a remote network connection, or via a computer readable storage media (i.e., flash memory, DVD/CD ROM, floppy disk, removable or permanent hard drive etc.). In some implementations, the application 210 may be a "plug-in" application that is incorporated into a third-party software application including, for example, document-processing or image production applications. Other configurations may be also implemented.

The graphical user interface module 220 is configured to generate a graphical user interface (GUI) on a display device and to control the various display and input/output (I/O) features of the application. The graphical user interface module 220 may generate display signals to the display device. In one implementation, it may provide one more "windows" or panes for displaying information to the user. The display device may include a cathode ray tube (CRT), liquid crystal display (LCD), plasma, or other display devices.

Moreover, the graphical user interface module 220 allows the user to interact with the application 210. For example, the graphical user interface module 220 may permit use and operation of one more of: a keyboard, keypad, touch-screen, mouse, joystick, light pen, or other peripheral devices for receiving inputs from a user. Similarly, the application may output information and data to the user, for example, via a printer or other peripheral device (e.g., external storage device or networked devices).

The graphical user interface module 220 may interact with a computer's operating system and/or one or more other software applications. In one implementation, application 210 may comprise a stand-alone software application running on a computer, printing system, or other machine. Alternatively, a server (not shown) may host the application 210, which may, in some implementations require a user to access the server over a network to use the application. In some implementations, a user may download the application 210 from a server, with program updates made available (over the network or the Internet) as needed, or on a predetermined, regularly-scheduled basis. The application 210 may be operated in a Microsoft Windows® operating environment. However, other operating systems and environments (e.g., UNIX, Linux, and proprietary systems, such as Apple Mac OS X) are also envisioned.

The spot color selection module 230 provides the user with capabilities to select one or more spot colors. For instance, the module 230 may display, in the graphical user interface, information regarding one or more spot colors for which the user may "tag" or otherwise select for consideration. An input device may be used by the user to do so.

The color selection module **230** may interface with at least one spot color database **235**, which stores or maintains color palettes, libraries, collections, and/or other information regarding spot colors. The spot color database **235** could be in some implementations located remotely from the application **210** and interface, for example, via a network. In one implementation, the spot color selection module **230** may also permit users to create new spot color entries and save and edit entries in the spot color database **235**.

The illuminant selection module **240** provides the user with capabilities to select one or more light sources for consideration. For instance, the module **240** may display, in the graphical user interface, information regarding light sources and illuminants for which the user may “tag” or otherwise select for consideration. The illuminant selection module **240** may interface with at least one illuminant database **245**, which stores or maintains spectral data for one or more light sources.

There is a variety of light sources available in the market. See, e.g., “Explanation of Visual Light Sources and Their Use in Visual Color Matching Applications,” GTI Graphic Technology, Inc., herein incorporated by reference in its entirety. Some of the light sources may comply with CIE ratings and/or have the ability to reproduce daylight in both visible and ultraviolet spectrums. Spectral models of the light sources based on color temperature are also available. In addition to collecting the spectra for known light sources, light measurement sensors may be to determine the spectra for non-standard light sources.

Many retail companies such as, for example, Wal-Mart, Target, Sears, and Home-Depot, have established specifications for the light sources used in their stores. Collecting various spectra may be done as a one-time process. Existing entries may be subsequently modified and/or new entries may be added to the illuminant database **245**, as desired.

Other spectral distribution data may be obtained from various resources. For example, many light source manufacturers may provide spectral distribution information on their products. Alternatively or additionally, spectral data may be collected empirically, for example, using an illuminant sensor, if the spectral distribution information, is not otherwise available.

The device specific recipe module **250** interfaces with the printing system **270** and is configured to generate nominal device recipe information for printing spot colors with the printing system **270**. This module **250** may initiate commands to the printing system **270** to render one or more test patterns or patches corresponding to the nominal device recipe information.

The printing system **270** may include any print engine capable of color printing technology such as, for example, ink-jet (bubble jet), laser, offset, solid-ink, dye sublimation, xerography, etc., in which color is rendered by using a plurality of process colors (e.g., CMYK). In some implementations, the spectral sensor **280** may be used in conjunction with the printing system **270**, such as an embedded or inline spectrophotometer (ILS).

The spectral sensor **280** is configured to measure the spectra of printed test patterns. Spectra from color test patterns and patches printed by the printing system **270** may be measured using a spectrophotometer using a broadband illumination source, such as, a fluorescent lamp. See, for example, U.S. Pat. No. 6,639,669, herein incorporated by reference in its entirety. The spectral sensor **280** might also be separate or offline from the printing system **270**.

The recipe optimizer module **260** is configured to determine an optimal recipe for each spot color under various

illuminants considered. This module **260** may be used for performing one or more methods for adaptive illumination independent matching of one or more spot colors in accordance with embodiments disclosed herein. For instance, an iterative process may be utilized until the target and measured spectral values satisfactorily converge to within a predetermined tolerance.

In one implementation, the color dispersion is measured as average delta-E 1976 and/or average delta-E 2000, wherein multiple iterations are carried out to converge to a single recipe at a particular illuminant.

The optimized recipe information for spot colors under various illuminants under consideration may be stored or maintained on an adaptive illumination independent spot color matching database **265**. In other implementations, though, the optimized recipe data may be stored or maintained alternatively or additionally, in the spot color databases **235** or the illuminant databases **245**. In fact, the databases and information therein may be combined.

The optimized recipe information may then be transmitted to a color management profile in the memory of the printing system **270**. When desired, the printing system may print or display a spot color using the optimized recipe information.

In addition, the module **260** may automatically choose and/or recommend the optimal recipe that provides lowest color dispersion across a variety of spectra under consideration. Results may be displayed in the display device of the graphical user interface.

An illumination sensor **290** may also be provided. For instance, a Model LUX LITE Visible radiation sensor manufactured by Kipp & Zonen, B.V., and distributed by Climatronics Corp. This particular sensor has a spectral characteristic, which is in accordance with the CIE (Commission International d’Eclairage) requirements. This sensor includes a photodiode sensor and a filter which provides a spectral response similar to that of the average human eye. Although, it will be appreciated that other color and spectral sensors may also be used. The location and distance from the light source may vary depending on the light source and/or environ.

FIG. 3 shows an exemplary method **300** for adaptive illumination independent matching of one or more spot colors according to an embodiment.

The method begins in step **310**. In step **320**, spectra for a spot color is obtained. Each spot color, depending on the industry, proprietary, and/or organizational system, has a characteristic spectra. Typically, the spot color may be described as being within a color space such as a reflectance (or transmittance) spectra over the visible light spectrum, $L^*a^*b^*$, XYZ, LHC, CMYK, RGB, or sRGB. These spectra may be retrieved from a spot color database **235** or otherwise provided. As noted above, these values are generally provided for only a 2 degree observer and a D50 light source. One or more spot colors may be selected by a user for consideration via spot color selection module **230**. If multiple spot colors are selected, the method uses either first or next selected spot color.

In step **330**, illuminant spectra for a plurality of illuminants are obtained. Illuminant spectral data may be stored in one or more illuminant databases **245** and one or more illuminants may be selected by the user via illuminant selection module **240**. In some implementations, all light sources in the illuminant database will be considered, although, it will be appreciated that not all illuminant spectra in the illuminant database(s) **245** need to be utilized. For instance, a user may select a plurality of light sources (or spectra), from the illuminant spectra database **245** for consideration. In some implementa-

tions, the illuminant spectra may be measured in situ, using the illumination sensor 290 (FIG. 2).

Next in step 340, a device specific recipe for the selected spot color is calculated for each of the illuminants sampled. One implementation of this process is disclosed in more detail in FIG. 4.

The spot color spectra may be converted to an illuminant specific target value for each of the illuminants sampled. In one implementation, the target values may be CIE L*a*b* values. This may be performed, for instance, using an ICC

profile. Then device specific recipes are calculated corresponding to the target values for the particular printing system for each illuminant.

Using the printing system 270 (FIG. 2), test patterns having the device specific recipes are printed and measured with the sensor 280 to determine their spectral profile.

If the color dispersion between the target values and the measured values of the test pattern for a particular illuminant is within a predetermined tolerance, that recipe is kept. Otherwise, the recipe is altered. For example, delta-E 1976 and/or delta-E 2000 values may be calculated for the color differences between the target values and the measured values. Step 340 may continue multiple times, as needed, until the target and measured values for that illuminant satisfactorily converge to within to a predetermined tolerance.

In step 350, for each of the device specific recipes obtained in step 340, color dispersion values may be calculated for that same device specific device for all the remaining illuminants (other than the particular illuminant used to determine the device specific recipe in step 340). One implementation of this process is disclosed in more detail in FIG. 5.

It is to be noted that, in some implementations, a well known quantity called a Color Inconstancy Index (CII) may be used to measure the extent of color inconstancy of a sample under different illuminants. That is, the Color Inconstancy Index is the total color difference for a sample between reference illuminant and other testing illuminants. By using ASCE or other spot color recipe search methods for the printing system one can obtain a set of colorants such as CMYK that best match the reference color under the reference illuminant. A simplified CII may be calculated as the color difference between reference and testing illuminants using any color difference equation. For example, the CII for sample #1 between D50 light source and D65 light source can be written as:

$$CII = \sqrt{(L_{D50_Sample1} - L_{D65_Sample1})^2 + (a_{D50_Sample1} - a_{D65_Sample1})^2 + (b_{D50_Sample1} - b_{D65_Sample1})^2}$$

where L, a and b values correspond to L*, a* and b* values with suffixes corresponding to D50 illuminant and D65 illuminant for sample 1. Color inconstancy indicates the degree to which the appearance of sample's color changes when the illuminant is changed. Color inconstancy can be determined by measuring the sample with an instrument under different illuminants and then performing mathematical calculations.

Yet as another example of the color dispersion value, the spectra of a reference color such as a Pantone® color may be used to calculate the target L*a*b* value under a reference

illuminant and an observer angle. Using ASCE or other spot color recipe search methods for the printing system one can obtain a set of colorants such as CMYK to best match the target L*a*b* under the reference illuminant and the observer angle. When viewed under a different illuminant or a different observer angle, the spot color from the printing system may deviate from the reference color. This deviation or color dispersion may be referred to as the Reference Color Difference Quantity (RCDQ). Mathematically the CIE deltaE version of the RCDQ is

$$RCDQ(I_R, I) = \sqrt{(L_I(sp_R) - L_I(CMYK_{I_R}))^2 + (a_I(sp_R) - a_I(CMYK_{I_R}))^2 + (b_I(sp_R) - b_I(CMYK_{I_R}))^2}$$

and the deltaE2000 version of the RCDQ is

$$RCDQ(I_R, I) = \text{deltaE2000}[L_I(sp_R)a_I(sp_R)b_I(sp_R), L_I(CMYK_{I_R})a_I(CMYK_{I_R})b_I(CMYK_{I_R})]$$

where I stands for the illuminant under consideration, I_R stands for the reference illuminant, sp_R is the spectra of the reference color, and $CMYK_{I_R}$ is the CMYK value obtained by the spot color recipe search methods that best match the reference color under the reference illuminant. For example, if I_R is chosen as the D50 illuminant, then $L_I(CMYK_{I_R})$ is the L* value of the measured spot color for illuminant I (D65, D75 etc.) which is produced with a recipe ($CMYK_{I_R}$) at D50 illuminant. $L_I(sp_R)$ is the target L* value of the target spot color spectra under illuminant I. Similarly a* and b* values are calculated and RCDQ numbers are obtained corresponding to those illuminants. The RCDQ value measures the ability of the printing system to re-produce colors under various illuminant condition which is expressed using well known color difference equations such as CIELab or deltaE2000. For example, if $CMYK_{I_R}$ of the printing system produces the spectra that matches exactly sp_R (i.e., with zero deltaE) then RCDQ will be zero under any illuminant condition. In one implementation (for example in FIG. 1a), for variety of illuminants, RCDQ numbers are obtained with D50 illuminant as the reference light source at fixed observer angle of 2 degrees. A maximum or average RCDQ number is obtained from these calculations for the reference illuminant to understand sample's color dispersion value across different illuminants. These calculations may be performed across the remaining illuminants with second illuminant as the reference (e.g., D65). One RCDQ number is obtained for the second reference illuminant. Repeating these calculations across the remaining illuminants with one of them as the reference each time gives sample's color dispersion value (average, 95 percentile or maximum RCDQ number) across variety of illuminants in the database.

In addition, it is to be noted that the color dispersion value may be, in some implementations, expressed as another well known quantity called a Metameric Index, which is a single-number index which indicates how well two materials (for example, two spectra; target spectra and measured spectra) match under two different illuminants. The spectral curves of two closely matching, non-metameric samples are nearly identical. Metameric index is used to measure the degree of metamerism. It is calculated with respect to two different illuminants. Metamerism Index is based on Hunter L,a,b values and is shown below

$$MI = \sqrt{(\Delta L_{n1} - \Delta L_{n2})^2 + (\Delta a_{n1} - \Delta a_{n2})^2 + (\Delta b_{n1} - \Delta b_{n2})^2}$$

where n_1 is the first illuminant and n_2 is the second illuminant and $\Delta = \text{Value}_{\text{target}} - \text{Value}_{\text{measured}}$. For example, L^* differences between two illuminants can be calculated as: $\Delta L_{n1}^* = (L_{\text{target}}^* - L_{\text{measured}}^*)_{n1}$ for first illuminant and $\Delta L_{n2}^* = (L_{\text{target}}^* - L_{\text{measured}}^*)_{n2}$ for second illuminant. Similarly a^* differences and b^* differences can be calculated for two different illuminants. The metameric index represents how well the colors are spectrally matched for two different illuminants. The target spot color spectra and the measured spectra obtained after using the best color recipe may be used as samples to see how well they are spectrally matched (or reproduced for minimizing metameric index). When the measured spectra perfectly matches with the target spectra, the metameric index will be zero. This may, however, not be true in practice due to limited choice of device specific recipe (or colorants).

In step 360, the optimal recipe for the device specific recipes for each spot color that yields the minimum color dispersion across all the illuminants sampled is determined. For instance, this may be the recipe that gives the minimum delta-E variation across the plurality of illuminants considered. The method ends in step 370.

In one implementation, the illumination sensor 290 (FIG. 2) may be used to provide the best color matching using illuminant spectral distribution measured directly from a light source. The illumination sensor may be used to directly measure lighting in situ to obtain a spectra in step 330. For instance, the illumination sensor 290 may be located in a room or other environ in which the spot color is typically viewed. The location and distance from the light source may vary depending on the light source and/or environ.

FIG. 4 shows an exemplary method 400 for determining device specific recipes for a spot color according to an embodiment. This method is one implementation of step 340 in FIG. 3.

The method begins in step 410. In step 420, a spot color spectra is converted to an illuminant specific target value for an illuminant sampled. In one implementation, the target values may be CIE $L^*a^*b^*$ values. This may be performed, for instance, using an International Color Consortium (ICC) profile.

In one implementation, CIE XYZ color space may be first determined, according to equations (1) to (3), below:

$$X = 100 \frac{\sum_{k=0}^{N-1} \bar{X}(\lambda_k) R(\lambda_k) I(\lambda_k)}{\sum_{k=0}^{N-1} \bar{Y}(\lambda_k) I(\lambda_k)} \quad (1)$$

$$Y = 100 \frac{\sum_{k=0}^{N-1} \bar{Y}(\lambda_k) R(\lambda_k) I(\lambda_k)}{\sum_{k=0}^{N-1} \bar{Y}(\lambda_k) I(\lambda_k)} \quad (2)$$

$$Z = 100 \frac{\sum_{k=0}^{N-1} \bar{Z}(\lambda_k) R(\lambda_k) I(\lambda_k)}{\sum_{k=0}^{N-1} \bar{Y}(\lambda_k) I(\lambda_k)} \quad (3)$$

In the above equations, $\bar{X}(\lambda)$, $\bar{Y}(\lambda)$, and $\bar{Z}(\lambda)$ are the CIE color matching functions, $R(\lambda)$ is the reflectance spectra of the measured test pattern for the spot, and $I(\lambda)$ is the spectra of the desired light source.

The CIE $L^*a^*b^*$ color space values may then be obtained from CIE XYZ using the nonlinear transformations according to equations (4)-(6):

$$L^* = 116 f\left(\frac{Y}{Y_n}\right) - 16 \quad (4)$$

$$a^* = 500 \left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right) \right] \quad (5)$$

$$b^* = 200 \left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right) \right] \quad (6)$$

where

$$f(x) = \begin{cases} x^{\frac{1}{3}} & x \geq 0.008856 \\ 7.787x + \frac{16}{116} & x \leq 0.008856 \end{cases}$$

and X_n , Y_n , and Z_n are tristimulus values of a reference white point. For additional information regarding such conversions, see for example, Appendix A of L. K. Mestha and S. A. Dianat, Control of Color Imaging Systems, Publisher: CRC Press, ISBN 978-0-8493-3746-8, May 2009, herein incorporated by reference in its entirety.

While CIE LAB color space is disclosed, it will be appreciated that other device-independent color spaces may be similarly used, such as, for example, CIE $L^*u^*v^*$, LCH, etc.

In some implementations, the spot color may be outside the printer gamut. If so, the $L^*a^*b^*$ values may be mapped to the printer gamut based on a gamut mapping strategy (e.g., minimum delta-E). One ray-based gamut mapping strategy is described below. (See FIG. 6). However, it will be appreciated that other mapping strategies may similarly be used. The mapped values then become the new target.

Continuing to step 430, the device specific recipes are calculated corresponding to the target values for the particular printing system. For example, an ICC inverse printer model or look up table (LUT) may be used. The device specific recipe may include the constituent proportions of the process colors, which the printing system uses in color printing. In four-color printing, typically cyan, magenta, yellow and black (CMYK) colorants are used. In some implementations, additional process colors may also be used, such as orange (O) and/or violet (V). Although, it will be appreciated that the number of process colors may vary by the manufacturer, and/or the printer operator.

In step 440, at least one color test pattern corresponding to the device specific recipe, which was calculated in step 430, is printed and measured. In one implementation, the color test pattern may be printed as a solid-high density test patch, for instance a 1x1 inch square at high density (e.g., 100% toner area coverage). Other test pattern configurations are also possible.

The printed test pattern is measured using the spectral sensor 280 (FIG. 2) in step 450. As previously discussed, the spectral sensor 280 may be inline or embedded within the printing system 270. Thus, printing and measurement may be performed together in an automated manner to increase effi-

ciency. Alternatively, the spectral sensor could be separate or offline with respect to the printing system 270.

Next, in step 450, the target value and the measure value for the spot color are compared. For example, delta-E 1976 and/or delta-E 2000 values may be calculated for the color difference between the target values and the measured values.

A determination is made, in step 460, to see if the error between the target values and the measured value of the test pattern is within a predetermined tolerance (e.g., 1.5 delta-E2000).

If not, then the recipe may be adjusted in step 470 and the process returns to step 440. In one implementation, the Xerox Corp. "Automated Spot Color Editing (ASCE)" control process may be used. Details of this process are disclosed in U.S. Pat. No. 6,744,531, herein incorporated by reference in its entirety. This iterative process may be used to vary the device specific recipe until the error between the target value and the measured value is within a predetermined value. For example, steps 440 to 460 may be repeated, as necessary, until target values and the measured value of the test pattern is within the predetermined tolerance. Otherwise, the process continues to step 490 and ends at this step. It will be appreciated that other device specific recipe adjustment models may be similarly used.

In step 480, a determination is made whether there are more illuminants to consider. If yes, the process returns to 420. If not, the process ends in step 490.

It will be appreciated that while FIG. 4 shows a sequential process for determining device specific recipes for a spot color for each illuminant, that in other implementations, this could be performed in parallel, with the printing and measuring of multiple test patterns for various illuminant specific values occurring at substantially the same time.

FIG. 5 shows an exemplary method 500 for calculating maximum color dispersion values for all illuminants according to an embodiment. This is one implementation of step 350 in FIG. 3.

The method begins in step 510. In step 520, the device specific recipe for the spot color for a particular illuminant (obtained in step 340) is then applied to a next illuminant among the remaining illuminants. The spectra corresponding to the device specific recipe may be determined using the printer model for the device specific recipe.

Next in step 530, the spectra obtained from the printer model in step 520 is converted to an illuminant specific $L^*a^*b^*$ value for the other illuminant, for example, using equations (1)-(6), discuss above.

Similarly, in step 540, the target spectra for the spot color under the illuminant considered (also obtained in step 420) is similarly converted to an illuminant specific target value for the another illuminant, for example, using equations (1)-(6).

In step 550, the difference between the converted illuminant specific values (from step 530) and the converted target value (from step 540) is determined, for example, in delta-E1976 and/or delta-E2000.

Next in step 560, a determination is made whether there are more illuminants to consider. If yes, the process returns to 520. If not, the process goes to step 570, where the maximum difference value (for example, maximum RCDQ value) is selected for the color difference values, for example, in delta-E1976 and/or delta-E2000, for each of the illuminants. The process ends in step 580.

FIG. 6 shows an exemplary ray-based gamut mapping method 600 for determining device specific for a given light source according to an embodiment.

The method begins in step 610. In step 620, a target values for a particular spot color are obtained. The device indepen-

dent color space values may be, however, out-of-gamut under a set of illuminants that represent various viewing conditions. In one implementation, a determination may be made whether an illumination sensor is available for use. If yes, step 620 may obtain the illumination specific target values by directly measuring illuminant spectra using the illumination sensor.

In step 630, a ray may be "drawn" for each illuminant between the device independent color space (e.g., $L^*a^*b^*$) value obtained in step 620 and the focal (or center) point of the printer gamut. For instance, this may correspond to $L=50$, $a=0$, $b=0$. A similar approach is disclosed in U.S. patent application Ser. No. 12/291,473 mentioned above, which describes a ray based control model for a D50 light source and 2 degree observer using a printer model or by iterating on the printer.

Next in step 640, the gamut mapped $L^*a^*b^*$ value and the recipe for the out-of-gamut $L^*a^*b^*$ for each of the illuminants may be determined by searching the points along a ray that separates the in-gamut color from out-gamut color. While iterating on the printer model, each illuminant specific printer model whose inputs are device specific color space values (e.g. CMYK(OV)) and outputs are illuminant specific values (e.g. $L^*a^*b^*$) obtained from the spectral model. While iterating on the printer, illuminant specific values ($L^*a^*b^*$) may be obtained from the spectral measurements.

In step 650, color variation values (e.g., RCDQ values) are compared with each recipe under all illuminants as in step 620. The one with the smallest variation may be selected as the optimal recipe since it will provide the lowest dispersion.

At step 660, a determination is made as to whether there are more illuminants to consider. If yes, steps 620 to 650 may be repeated, as necessary, until a recipe is found for each light source considered. They are collected and may be stored in the illuminant database. Otherwise, the method ends in step 670.

In one implementation, if a particular spot color is known a priori from the adaptive illumination independent spot color matching database 265, then steps 620 to 650 may be used to identify the illuminant spectra that leads to the recipe with lowest dispersion for that spot color. For example, referring to FIG. 13, the D75 light source gives the lowest dispersion for the Pantone® 3385C spot color. For subsequent print runs with this spot color, using the D75 light source would be better than using the D50 light source.

FIG. 7 shows exemplary data for a Pantone® 202c spot color which is included in the printer gamut. The simulated data is based on the spot color when observed as 2 degree and 10 degree observers across 43 different illuminants. Column 1 of data indicates the illuminants. These include illuminants D36 to D75, White LED, and the fluorescence lamps, Firestar and Stirling.

Columns 2 and 3 show the maximum delta-E 1976 and delta-E 2000 dispersion values for each illuminant, respectively. And columns 4-7 show the optimized CMYK device specific recipes for the spot color that were calculated for each illuminant.

When an illumination sensor is available, the device specific recipe that gives the lowest error may be determined that indicates the best color match to the Pantone® target spectra. On the other hand, if an illumination sensor is not available, then ASCE spot color iterations may be carried out across all the illumination spectra considered to determine the maximum delta-E dispersion (i.e., maximum RCDQ value).

To obtain the lowest dispersion depends on the delta-E criteria that were used for comparing the output color with the target color. For instance, if delta-E 1976 is selected as the

criteria, recipes from D53 row would be optimal. On the other hand, if delta-E 2000 is selected as the criteria, then the recipe from D46 light source will be optimal.

In both cases, the D50 light source recipe, for example, is not the most optimal recipe to achieve the best color match across a population of light sources, even though, its recipe is just one digital count apart.

FIG. 8 shows data for a Pantone® 321 spot color which is outside of the printed gamut. Delta-E values were calculated with respect to out-of-gamut-mapped Lab color space values. The maximum delta-E 1976 dispersion is lowest for the D67 illuminant and maximum delta-E 2000 dispersion is lowest for D75 illuminant. Again, the corresponding recipes give a much better illumination independent spot color recipe than the standard D50 light source recipe.

FIG. 9 shows a representative of the printer gamut for spot color under different illuminants.

Specifically, a Pantone® 251C spot color was used to illustrate the effects of a CMYK recipe under 47 different illuminants. These included standard illuminants A, B, C, E, D36 to D75, White LED, and the fluorescence lamps, Firestar and Stirling. The printer was modeled by the Neugebauer model appropriate form the Xerox Corp. iGen3®. Shown together are the $L^*a^*b^*$ values of the Pantone® 251C spot color (i.e., the solid triangles).

The D50 illumination (solid), for instance, is different from the Stirling fluorescence lamp (wire-bond). These gamut changes between the two may be large. For example, the shift at the blue tip of the gamut is about 20.4 delta-E1976 (or 7.4 delta-E2000) between the illuminants.

The Pantone® 251C color is mapped to the printer gamut boundary for each illuminant, for example, by the method described in U.S. patent application Ser. No. 12/291,473, mentioned above. A line may be drawn between the spot color and a focal point of the gamut. For example, this may correspond to $L=50, a=0, b=0$. Next, the line was divided into 100 segments, and each node of the segments because the targets for control based iterations. If the node is inside the printer gamut for a given illuminant, then control based iteration will determine a zero or near zero difference between the target and the output color. Otherwise, there will be a steady state value (i.e., non-zero value).

FIG. 10 shows each curve this difference for all nodes for a given illuminant. The mapping point is the “knee” (i.e., the sudden rise or breakaway point) of the curve, and the device specific recipe that is associated with the knee is the gamut mapped value.

The dispersion of the colors from the CMYK recipe at the knee of the curve for different illuminants are shown in FIGS. 11(a) and FIG. 11(b). FIG. 11(a) show the dispersion of the gamut mapped recipe from a Stirling light source for the Pantone® 251C spot color. It is noted that the specific points depicted in the plots correspond to the different illuminants under consideration.

FIG. 11(b) shows delta-E1976 and delta-E2000 values across multiple illuminants for the Pantone 3385C spot color when spot color mapping is done for a Stirling light source and 2 degree observer.

FIG. 12 shows the maximum dispersion of each recipe for the Pantone® 251C spot color. The recipe with the smallest maximum dispersion will give the least color variation under a variety of illumination conditions. It is this case, that the illuminant independent mapping recipe for the Pantone® 251C spot color is $CMYK=[69\ 120\ 0\ 3]$, which occurs at around the D55 and D56 light sources.

FIG. 13 shows the maximum dispersion of each recipe for a Pantone® 3385C spot color. In this example, that the illu-

minant independent mapping recipe for the Pantone® 3385C spot color is $CMYK=[160\ 0\ 102\ 2]$, which occurs at D75 illuminant.

While this disclosure has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that it is capable of further modifications and is not to be limited to the disclosed embodiments, and this disclosure is intended to cover any variations, uses, equivalent arrangements or adaptations of the inventive concepts following, in general, the principles of the disclosed embodiments and including such departures from the present disclosure as come within known or customary practice in the art to which the embodiments pertains, and as may be applied to the essential features hereinbefore set forth and followed in the spirit and scope of the appended claims.

What is claimed is:

1. A method for adaptive illumination independent matching of spot colors for a printing system, the method being implemented in a computer system comprising one or more processors configured to execute one or more computer program modules, comprising:

obtaining spectra for at least one spot color;

obtaining illuminant spectra for a plurality of illuminants; converting, using the one or more processors, the at least one spot color spectra to an illuminant specific target value corresponding to each of the plurality of illuminants;

determining, using the one or more processors, a device specific recipe for the at least one spot color for each of the illuminant specific target value for the printing system, wherein each of the determined device specific recipe corresponds to each of the plurality of illuminants;

for each of the determined device specific recipes, calculating, using the one or more processors, color dispersion values for that same determined device specific recipe for all the remaining of the plurality of illuminants other than the illuminant used to determine the device specific recipe; and

using the calculated color dispersion values to select a device specific recipe for the at least one spot color from the determined device specific recipes of the at least one spot color, wherein the selected device specific recipe for the at least one spot color yields a lowest color dispersion value across all of the plurality of illuminants.

2. The method according to claim 1, wherein determining the device specific recipe for each of the target value comprises:

calculating a device specific recipe for a target value; printing, via the printing system, a test pattern according to the device specific recipe;

measuring, via a spectral sensor, a value of the printed test pattern; and

adjusting the device specific recipe, and printing and measuring test patterns according to the adjusted recipe, as needed, until the target and measured value are within a predetermined tolerance.

3. The method according to claim 1, wherein calculating the color dispersion value comprises:

calculating a maximum color dispersion for each of the plurality of illuminants based on the device specific recipes; and

selecting a device specific recipe for the at least one spot color that yields the minimum of the maximum color dispersion across the plurality of illuminants.

15

4. The method according to claim 1, wherein calculating the color dispersion value comprises:
 calculating an average or 95 percentile color dispersion for each of the plurality of illuminants based on the device specific recipes; and
 selecting a device specific recipe for the at least one spot color that yields the minimum of the average or the 95 percentile color dispersion across the plurality of illuminants.
5. The method according to claim 1, wherein the color dispersion value is a metamerism index and the recipe is selected according to the minimum of the metamerism index.
6. The method according to claim 1, wherein the color dispersion value is a reference color difference quantity and the recipe is selected according to the minimum of the reference color difference quantity.
7. The method according to claim 1, wherein the color dispersion value is a color inconsistency index and the recipe is selected according to the minimum of the color inconsistency index.
8. The method according to claim 1, further comprising: storing the selected recipes in a memory device or displaying the selected recipes via a graphic user interface.
9. The method according to claim 1, further comprising: using an illumination sensor to obtain the spectra for at least one illuminant.
10. The method according to claim 1, further comprising: receiving, from at least one database, spectra for at least one illuminant.
11. The method according to claim 1, wherein the target and measured value are CIE $L^*a^*b^*$ values.
12. The method according to claim 1, further comprising: receiving, from at least one database, spectra for at least one spot color.
13. The method according to claim 1, wherein the color dispersion is measured in delta-E 1976 or delta-E 2000.
14. The method according to claim 1, wherein the color dispersion is measured as an average delta-E 1976 or average delta-E 2000, and determining a device specific recipe for each of the target value for the printing system comprises performing multiple iterations to converge to a single recipe at a particular illuminant.
15. The method according to claim 1, wherein obtaining spectra for the at least one spot color comprises:
 mapping the at least one spot color to a gamut of the printing system.
16. The method according to claim 15, further comprising: performing a ray-based gamut mapping technique.
17. The method according to claim 16, wherein the ray corresponds to a value of $L=50, a=0, b=0$, measured in LAB color space, in the gamut.
18. The method according to claim 16, further comprising: searching points along a ray that separates the in-gamut color from out-gamut color to determine the mapped color in the gamut.
19. The method according to claim 1, wherein obtaining spectra for the at least one spot color comprises: mapping the at least one spot color to a gamut of a display device.
20. A system for adaptive illumination independent matching of spot colors for a printing system comprising:
 a print engine configured to render color;
 a sensor configured to measure spectra for a printed color; and
 a processor configured to:
 (i) convert at least one spot color spectra to an illuminant specific target value corresponding to each of a plurality of illuminants;

16

- (ii) determine a device specific recipe for the at least one spot color for each of the illuminant specific target value for the printing system, wherein each of the determined device specific recipe corresponds to each of the plurality of illuminants;
- (iii) for each of the determined device specific recipes, calculating color dispersion values for that same determined device specific recipe for all the remaining of the plurality of illuminants other than the illuminant used to determine the device specific recipe; and
- (iv) use the calculated color dispersion values to select a device specific recipe for the at least one spot, color from the determined device specific recipes of the at least one spot color, wherein the selected device specific recipe for the at least one spot color yields a lowest color dispersion value across all of the plurality of illuminants.
21. The system according to claim 20, wherein in determining a device specific recipe for each of the target value the processor is configured to:
 calculate device specific recipe for a target valuespectra;
 print, via the printing engine, a test pattern according to the device specific recipe;
 measure, via a spectral sensor, a value of the printed test pattern; and
 adjust the device specific recipe, and printing and measuring test patterns according to the adjusted recipe, as needed, until the target and measured value are within a predetermined tolerance.
22. The system according to claim 20, wherein in calculating the color dispersion value the processor is configured to:
 calculate a maximum color dispersion for each of the plurality of illuminants based on the device specific recipes; and
 select a device specific recipe for the at least one spot color that yields the minimum of the maximum color dispersion across the plurality of illuminants.
23. The system according to claim 20, wherein the color dispersion value is a metamerism index.
24. The system according to claim 20, further comprising: an illumination sensor configured to obtain the spectra for at least one illuminant.
25. The system according to claim 20, further comprising: at least one database configured to store spectra for at least one illuminant.
26. The system according to claim 20, wherein the target and measured values are CIE $L^*a^*b^*$ values.
27. The system according to claim 20, further comprising: at least one database configured to store spectra for at least one spot color.
28. The system according to claim 20, wherein the color dispersion is measured in delta-E 1976 or delta-E 2000.
29. The system according to claim 28, wherein the color dispersion is measured as an average delta-E 1976 or average delta-E 2000, and in determining a device specific recipe for each of the target value for the printing system the processor is configured to perform multiple iterations to converge to a single recipe at a particular illuminant.
30. The system according to claim 20, wherein in obtaining spectra for the at least one spot color the processor is configured to map the at least one spot color to a gamut of the printing system.
31. The system according to claim 30, wherein the processor is configured to perform a ray-based gamut mapping technique.

17

32. The system according to claim 31, wherein the ray corresponds to a value of $L=50$, $a=0$, $b=0$, measured in LAB color space, in the gamut.

33. The system according to claim 31, wherein the processor is configured to search points along a ray that separates the in-gamut color from out-gamut color to determine the mapped color in the gamut. 5

34. The system according to claim 20, wherein in obtaining spectra for the at least one spot color the processor is configured to map the at least one spot color to a gamut of a display device. 10

35. A computer program product embodied on a non-transitory computer-readable storage medium encoded with computer instructions that when executed by a processor are configured to implement a method for adaptive illumination independent matching of spot colors for a printing system, the method comprising: 15

- obtaining spectra for at least one spot color;
- obtaining illuminant spectra for a plurality of illuminants;

18

converting, using the processor, the at least one spot color spectra to an illuminant specific target value corresponding to each of the plurality of illuminants;

determining, using the processor, a device specific recipe for the at least one spot color for each of the illuminant specific target value for the printing system;

for each of the determined device specific recipes, calculating, using the processor, color dispersion values for that same determined device specific recipe for all the remaining of the plurality of illuminants other than the illuminant used to determine the device specific recipe; and

using the calculated color dispersion values to select a device specific recipe for the at least one spot color from the determined device specific recipes of the at least one spot color, wherein the selected device specific recipe for the at least one spot color yields a lowest color dispersion value across all of the plurality of illuminants.

* * * * *